

## Introduction

The understanding of the structure of the nucleon is of fundamental importance; ultimately such an understanding is necessary to a first principle description of the nuclear force. The distribution of charge and currents inside the nucleon is best revealed by the electromagnetic probe, through the interaction of the virtual photon with the quark constituents of the nucleon.

Experiments to obtain information about the charge and current distribution of the nucleon have been carried out since the mid 1950's. The cross section for elastic scattering of unpolarized electrons on unpolarized nucleons is:

$$\frac{d\sigma}{d\Omega_e} = \frac{d\sigma}{d\Omega_{\text{Mott}}} [G_{\text{Ep}}^2(Q^2) + \tau G_{\text{Mp}}^2(Q^2) \{1 + 2(1+\tau)\tan^2(\theta_e/2)\}] \quad (1)$$

where  $\tau$  is related to the four-momentum squared  $Q^2 = -q_\mu^2$  by  $\tau = Q^2/4m_N^2$  and  $(d\sigma/d\Omega)_{\text{Mott}}$  is the Mott cross section for a structureless nucleon, given by:

$$\frac{d\sigma}{d\Omega_{\text{Mott}}} = (\alpha/2E_e)^2 \cos^2(\theta_e/2) / [1 + (2E_e/M)\sin^2(\theta_e/2)] \sin^4(\theta_e/2), \quad (2)$$

where  $E_e$  is the incident electron energy and  $\theta_e$  the electron scattering angle. The Sachs electric and magnetic form factors  $G_{\text{Ep}}$  and  $G_{\text{Mp}}$  are related to the Dirac and Pauli form factors  $F_1$  and  $F_2$  by:

$$G_E = F_1 - \tau F_2 \quad \text{and} \quad G_M = F_1 + F_2.$$

A complete description of the internal structure of the nucleon

requires determination of  $F_1$  and  $F_2$ , or equivalently  $G_E$  and  $G_M$ , for all values of four-momentum transfers  $Q^2$ . At the present time the form factors of the neutron are poorly defined at any  $Q^2$ ; it may appear surprising that even for the proton the electric form factor is not well determined experimentally beyond  $Q^2=1 \text{ GeV}^2$ .

Elastic ep differential cross sections have been measured by Arnold et al<sup>1</sup> up to four-momentum squared  $Q^2 \approx 31 (\text{GeV}/c)^2$ . However, the separate determination of  $G_{Ep}$  from a cross section measurement (see formula (1)) at large  $Q^2$  is difficult because of the dominance of the magnetic term. An important step was achieved by Litt et al<sup>2</sup> when they isolated  $G_{Ep}$  up to the large  $Q^2$ -value of  $3.75 \text{ GeV}^2$ , although with relatively large error bars. More recently, Walker et al<sup>3</sup> (SLAC experiment E140) separated both  $G_{Ep}$  and  $G_{Mp}$  up to  $Q^2 = 3 \text{ GeV}^2$  with error bars for  $G_{Mp}$  smaller than 3%; these data can be seen in fig. 1 taken from ref. 3. In the same figure we observe that error bars for  $G_{Ep}$  reaches  $\pm 13.8\%$  at  $3 \text{ GeV}^2$ , even though the statistical uncertainty is as low as 0.8%. This illustrates the difficulty in separating  $G_{Ep}$  from cross section data.

A new experiment at SLAC (NE-11) is expected to produce separated  $G_{Ep}$  and  $G_{Mp}$  form factors up to  $6 \text{ GeV}^2$ . The goals of this latest experiment, as stated in the proposal<sup>4</sup>, are for error bars of  $\pm 1.5 \%$  for  $G_{Mp}$  at  $Q^2$  between 2 and  $6 \text{ GeV}^2$  and for  $G_{Ep} \pm 4 \%$  near  $2 \text{ GeV}^2$ , increasing to  $\pm 17\%$  at  $5 \text{ GeV}^2$ .

The  $G_{Ep}$  results from ref. 3 are in disagreement with the older data of Bartel et al<sup>5</sup> which also went up to  $Q^2=3 \text{ GeV}^2$ . The new data indicate a slow rise of the ratio of  $G_{Ep}$  to the dipole

parametrization  $G_D$  with  $Q^2$ , and are in agreement with the data of Litt et al (ref. 2). It is thus important to verify the new data, and the present proposal shows that the measurement of  $G_{Ep}$  by the recoil polarization method will give total error bars (statistical plus systematical)  $\approx 4.5\%$  at  $4.5 \text{ GeV}^2$  and significantly smaller at smaller  $Q^2$ .

At the present the form factors of the nucleon are calculated within the framework of either the vector meson dominance model (VMD), or QCD based quark models. The VMD calculations have given predictions which for  $G_{Ep}$  tend to decrease below  $G_D$  with increasing  $Q^2$ . Examples of such calculations are seen in fig. 1 taken from ref. 3. The dashed curve is from Hoehler et al<sup>6</sup> and incorporates the  $\rho$ ,  $\phi$  and  $\omega$  mesons. The dotted line from Iachello et al<sup>7</sup> is also based on the VMD, and so is the low  $Q^2$  part for the solid curve from Gari<sup>8</sup>. A prediction by Radyushkin<sup>9</sup> based on QCD sum rule and assuming quark-hadron duality is also shown in fig. 1 with a dot-dash line. In fig. 2, taken from a preprint by Warns et al<sup>10</sup>, the solid line show a prediction for  $G_{Ep}$  and  $G_{Mp}$  based on a relativized quark model using the Isgur-Karl<sup>11</sup> baryonic wave function, and including a careful handling of the recoil corrections. The validity of the calculation is thought to extend to  $2.6 \text{ GeV}^2$ .

Although there is little doubt that nucleons and mesons are composed of quarks and gluons, it is less obvious that these ultimate components of the hadrons play a detectable role in the intermediate range of four-momentum transfers  $1 < Q^2 < 6 \text{ GeV}^2$ , which is

deuterium at  $Q^2$  between 0.26 and 0.53  $\text{GeV}^2$  <sup>14</sup> at Bates. A continuation of the Bates deuterium experiment at CEBAF is being proposed by the hall A collaboration<sup>15</sup>.

With the 4 GeV polarized beam at CEBAF,  $G_{Ep}$  can be measured by the recoil polarization technique out to 4.5  $\text{GeV}^2$ , with error bars 3-4 times smaller than the ones anticipated in the SLAC NE-11 experiment in approximately 60 days with a beam polarization  $h=0.4$ . With  $h=0.8$ , and for the same error bars, the required time would be 15 days. The characteristics of the pair of spectrometers in hall A are perfectly suited for this experiment which requires vertical angular resolution as good as  $\pm 1$  mr in the  $Q^2$ -region where the precession angle of the longitudinal polarization  $P_L$  is near  $180^\circ$ . An extension to 6  $\text{GeV}^2$  will become possible with a future increase of the beam energy to 6 GeV, without restriction from the 4 GeV/c limit of the spectrometers in hall A.

The coincidence experiment proposed here requires that the hadron arm be equipped with a focal plane polarimeter with good performance up to 3.2 GeV/c (2.4 GeV); the second phase would require an extension of the performance range of the polarimeter to 4 GeV/c (3.2 GeV).

We propose a self-calibration technique which does not depend critically upon independent calibration of the polarimeter analyzing power at these high energies. The method uses the simultaneous measurement of the sideways and longitudinal components of the proton polarization,  $P_s$  and  $P_L$ , and values of  $G_{Mp}$  from the existing or forthcoming data pool, at the same  $Q^2$  values

as the polarization measurement.

No recoil polarization experiment for elastic ep has been done in recent time; however an experiment using a polarized proton target has determined the sign of  $G_E/G_M$ <sup>16</sup> some time ago. With a focal plane polarimeter installed in the hadron arm of hall A at CEBAF, there will be an unique opportunity to measure  $G_{Ep}$  by the recoil polarization technique. The experiment requires a high power liquid hydrogen target; this proposal assumes 100  $\mu$ A on a 10 cm effective length. The kinematics we propose to measure are given in table 1, and the polarization components  $P_z$  and  $P_1$ , evaluated with dipole parametrization, are in table 2.